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MINISTRY OF AVIATION

EXPLOSIVES RESEARCH & DEVELOPMENT ESTABLISHMENT

TECHNICAL MEMORANDUM No. 10/M/62

Calorimetry of Double - Base Propellants: An Account of the E.R.D.E. Propellant Calorimeter Installation and Determination of Energy Equivalent

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1. Propellants, Double base.

Approved: G.K. Adams

G.K. ADAMS
S.P.R.

Approved for Circulation: C.H. Johnson

C.H. JOHNSON
DIRECTOR

17th August, 1962

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CONTENTS

Reference: WAC/139/09

1. SUMMARY

An account is given of a 150 ml. bomb calorimeter developed in E.R.D.E. and installed in Government propellant factories and Service Inspectorate laboratories for quality control and inspection in double-base propellant manufacture.

The preparation of a standard SC propellant and the measurement of its calorimetric value, using the combustion of benzoic acid in oxygen in a stainless steel bomb as standardising reaction, and the determination of the energy equivalent of the calorimeter with normal high-tensile steel bombs using this standard SC propellant are described.

Precision errors are of the order of 0.1 per cent.

2. INTRODUCTION

The rapid estimation by infrared gas analysis of the minor product methane in the combustion products enables the determination of calorimetric value to be used as a quality control test in the inspection of double-base rocket propellants.

By applying a correction for the methane and ammonium compounds formed, a 'corrected' calorimetric value can be computed which is independent of the particular installation involved in the measurement.

This memorandum describes the calorimetric apparatus developed in this Establishment and installed in the Government propellant factory and Service Inspectorate laboratories. An account is also given of work carried out two years ago in determining the energy equivalent of the E.R.D.E. calorimeters and in preparing a standard calorimetric propellant for distribution to other laboratories as a means of determining the energy equivalents of their own calorimeters.

3. DESCRIPTION OF THE E.R.D.E. CALORIMETER INSTALLATION

The routine calorimeter installation at Waltham Abbey consists of two twin-unit calorimeters. Photographs showing details of one of these twin-units are given in Figs. 1 - 9. Measurement of temperature is by platinum resistance thermometers of 40-ohm fundamental interval in conjunction with a Smith's No. 3 Difference Bridge (3). The whole installation is housed in rooms maintained at a constant temperature (20°C) and constant humidity (45 per cent r.h.).

The calorimeter bombs are of high-tensile steel and have a capacity of 150 ml. Fig. 2 gives the outside view, Fig. 3 shows the head and bomb interior and Fig. 4 the valve, insulated electrode and O-ring seal.

Fig. 5 shows the platinum resistance thermometer. The calorimeter can with stirrer and platinum resistance thermometer are shown in Fig. 6.

/The .....

The outer jacket or thermal shield with the bomb and resistance thermometer in position is shown in Fig. 7, whilst Fig. 8 gives a view of the interior of the water jacket, with heater, contact thermometer and thermostat.

Fig. 9 shows the firing panel, a Smith's No. 3 Difference Bridge and a Tinsley photocell galvanometer amplifier.

4. OPERATION OF APPARATUS

A propellant charge of 14.9 ± 0.001 g. is weighed into the bomb. A 2-inch length of 40 s.w.g. platinum wire is soldered to the electrode and underside of the bomb head and looped round 0.1 g. Mk. I cordite. The head is then screwed into the body with the valve open to release air. The valve is then closed.

The calorimeter can is placed in position. The bomb and resistance thermometer are placed in the can and the ignition leads connected. The firing circuit is tested for continuity and the resistance thermometer connected to the Smith's Bridge. Exactly 2,600 ml. water at 13°C are added from a calibrated measuring flask. The stirrers are started and the water in the calorimeter is raised to the initial temperature of firing by means of a small immersion heater. The initial temperature depends on the expected temperature rise for the propellant under test and is so chosen that the final temperature after firing is about 22°C, 1 degree below the outer jacket temperature.

The bridge is brought into balance and left for about 20 minutes until a steady rate of rise of temperature has been attained (about 0.010 deg.C per minute) then a stopclock is started and bridge readings recorded at one minute intervals. On the 10th minute the bomb is fired. No further bridge readings are taken until the 33rd minute when the bridge is re-balanced and readings are taken at minute intervals for a further 20 minutes. The rate of temperature rise during this period is of the order of 0.004 deg.C per minute.

On completion of the run, the calorimeter is dismantled and the bomb removed. The volume of gas in the bomb is measured by passing through a gas meter and the methane content determined with the infrared gas analyser (2). The bomb head is then removed, the liquid content is washed into a flask and the ammonium compounds estimated by titration with N/10 HCl solution.

5. COMPUTING THE EQUIVALENT TEMPERATURE RISE

The equivalent or true temperature rise which is the observed temperature rise corrected for heat of stirring and heat leakage is calculated from the initial and final temperature readings as described by Beck ((1) p. 6 and Appendix IV) for mercury-in-glass thermometers. A similar procedure is used for platinum resistance thermometers, the initial and final temperatures being recorded as resistance bridge readings. The equivalent temperature rise in bridge ohms is converted to degrees C, using the calibration factor of the resistance thermometer.

/The .....

The extrapolation time was determined for each of the series of firings referred to in Section 6 from the temperature/time curves of typical firings. Table 4 (p. 13) gives a summary of these times: the mean values so obtained were used in computing the equivalent temperature rise for all firings of the series.

In determining the extrapolation time from a particular firing, it is necessary to read temperatures throughout the experiment.

6. CALIBRATION OF APPARATUS

The energy equivalent of the calorimeters can most easily be determined by the combustion of a known weight of benzoic acid in oxygen. Since the high-tensile steel of the working bomb would be attacked by oxygen under the firing conditions, a more extended procedure is necessary involving the use of a stainless steel bomb for the benzoic acid combustion and the preparation of a standard SC propellant for calibrating calorimeter systems using high-tensile steel bombs.

Three series of firings were therefore carried out:

Series 1: Determination of the energy equivalent of the calorimeter by burning standard benzoic acid in oxygen in a stainless steel bomb.

Series 2: Determination of the calorimetric value of a standard SC propellant in the stainless steel bomb.

Series 3: Determination of the energy equivalent of the calorimeter with high-tensile steel bombs using the SC propellant as standard.

The means and precision errors of each series of 12 - 15 firings were then calculated.

Series 1 and 2 were carried out in the same bomb and calorimeter unit. To avoid unnecessary labour, the weights of the different bomb components, calorimeters and resistance thermometers of both twin-units were adjusted to be equal within narrow limits and could therefore be interchanged without altering the energy equivalent of any one combination (see Table 5, p.14). In Series 3, bombs, calorimeters and resistance thermometers were interchanged so that the energy equivalent finally obtained was a mean of all combinations used.

In Series 1, the Smith's Bridge was operated manually, whilst in Series 2 and 3 it was maintained in balance and the resistance readings recorded by means of an automatic device developed in this Establishment.

A more detailed account of the three series of experiments is given below.

/7. .....

7. PRECISION ERROR AND ESTIMATION OF UNCERTAINTY OF FINAL EXPERIMENTAL VALUES

The precision of the final experimental measurements was assessed according to the method described by Rossini (4).

The error of the calorimetric value of the SC propellant is a combination of the errors of the standard benzoic acid and of the measurements in Series 1 and 2.

The calibration error in Series 1:

$$c_1 = \pm 100 \times \frac{2(\Sigma\Delta^2/m(m-1))^{\frac{1}{2}}}{\text{energy equivalent (mean)}} \text{ per cent}$$

and the error in Series 2:

$$b = \pm 100 \times \frac{2(\Sigma\Delta^2/n(n-1))^{\frac{1}{2}}}{\text{calorimetric value (mean)}} \text{ per cent}$$

where $\Sigma\Delta^2$ = sum of the squares of the deviations of each measurement from the mean,

m = number of observation in Series 1,

n = " " " " Series 2.

The assigned precision error for the SC propellant is

$$d = \pm (e^2 + c_1{}^2 + b^2)^{\frac{1}{2}} \text{ per cent}$$

where e = "assigned error" of the standard benzoic acid.

A similar procedure is used in the determination of the energy equivalent of the calorimeters with the high-tensile steel bombs (Series 3) but in this case the SC propellant, of which the calorimetric value was obtained above, is used as the standard.

Calibration error in Series 3:

$$c_2 = \pm 100 \times \frac{2(\Sigma\Delta^2/p(p-1))^{\frac{1}{2}}}{\text{energy equivalent (mean)}} \text{ per cent}$$

where p is the number of observations in Series 3 and the corresponding precision error is

$$(d^2 + c_2{}^2)^{\frac{1}{2}} \text{ per cent.}$$

/The .....

The benzoic acid had been standardised at the National Physical Laboratory, Teddington and had a calorific value of 26,435 joules per gram with a standard error of 3 J/g.

From this it follows that the assigned error

$$e = 100 \times 2 \times \frac{3}{26435}$$

$$= 0.0227 \text{ per cent}$$

8. SERIES 1 - THE ENERGY EQUIVALENT OF THE CALORIMETER BY BURNING STANDARD BENZOIC ACID IN OXYGEN USING STAINLESS STEEL BOMB

This was determined by burning standard benzoic acid in oxygen in a 130 ml. Mk. XVI stainless steel bomb.

The standard benzoic acid was supplied by Messrs. British Drug Houses Ltd., (Batch No. 710,726) in the form of 0.19 g. pellets. The assigned calorific value was stated to be 26,425 joules per gram with a standard error of 3 J/g. corresponding to 6,318.1 thermochemical calories per gram with a standard error of 0.72 cal/g.

Oxygen, free of combustible impurities, was obtained by passing the normal commercial supply over copper oxide at 500°C, any combustion products being removed by Carbosorb. The purified oxygen was stored in 40 ft^3. gas cylinders.

1.1 - 1.2 gram (6 pellets) of benzoic acid was weighed into a platinum crucible. 1 ml. distilled water was added to the bomb from a pipette. A short piece of 40 s.w.g. platinum wire was connected across the electrodes and 4 inches of cotton thread weighed and looped over this wire. The crucible with benzoic acid was then fixed in its support and the cotton placed in contact with the pellets. The head was then screwed into position with the valve open.

The air in the bomb was then "rinsed" out by pressurising three times with commercial oxygen at 15 atmospheres and releasing the pressure. It was then pressurised to 15 atmospheres with "purified" oxygen, the pressure released and finally re-pressurised to 40 atmospheres and the valve closed.

The bomb was then placed in position in the calorimeter and the appropriate volume of water added, the actual weight added being obtained by weighing the measuring flask before and after delivery. The temperature of the water was raised to 19°C. The firing was then carried out as described in Section 4. Bridge readings were taken at 1-minute intervals during the first 10 minutes. After firing, the main period resistances were recorded by progressively increasing the bridge setting by e.g. 1 bridge ohm and recording the times when the bridge came into balance. On the 23rd minute after firing, minute readings were again taken until the 53rd minute.

The bomb was removed from the calorimeter, the gases released, and the head removed. The liquid contents were washed into a titrating flask with

/distilled .....

distilled water and the nitric acid titrated with N/10 caustic soda solution. The gaseous products were checked in each case for complete combustion by testing with a carbon monoxide detecting tube. There was no evidence of carbon monoxide in any of the firings.

In some instances there was a small amount of residual carbon in the crucible. This was weighed and a correction applied in the final calculation.

The results of 15 firings are summarised in Table 1 (p. 10). Column 4 gives the heat of combustion of standard benzoic acid under the conditions existing for that particular firing obtained from the formula (5):

$$f = 1 + 10^{-6}[20(P - 30) + 42(m_s/V - 3) + 30(m_w/V - 3) - 45(\theta - 25)]$$

where P = initial pressure of oxygen in atmospheres,

θ = temperature (C) to which the reaction is referred,

m_s = mass of benzoic acid in bomb in grams,

m_w = mass of water placed in the bomb in grams,

V = internal volume of bomb in litres.

Column 5 gives the equivalent temperature rise using a figure of 3.2 minutes as extrapolation time. The extrapolation time was obtained from Firings 4, 5, 6 and 7. Column 6 is the product of the weight of benzoic acid burned (Column 3) and the heat of combustion (Column 4).

Columns 7 and 8 give the heats evolved by combustion of cotton thread and the formation of nitric acid. Column 9 gives the correction for any residual carbon.

Column 10 gives the total energy divided by the equivalent temperature rise. Column 11 is the energy equivalent of the platinum crucible plus benzoic acid plus the amount by which the water in the calorimeter was in excess of 2598 grams. Column 12 is the energy equivalent of the standard initial system = Column 10 - Column 11.

The calibration error, c_1, is obtained by substituting the values in Table 1 in the expression (Section 7)

$$c_1 = \pm 100 \times \frac{2[\Sigma\Delta^2/m(m-1)]^{\frac{1}{2}}}{\text{energy equivalent (mean)}} \text{ per cent}$$

$$= \pm 100 \times \frac{2 \times 0.93}{4023.3}$$

$$= 0.0462 \text{ per cent.}$$

/9. .....

9. SERIES 2 - CALORIMETRIC VALUE OF A STANDARD SC PROPELLANT

This was determined in the Mk. XVI stainless steel cordite bomb. 50 lb. SC propellant 0.125-inch diameter (Lot RNP 1141S) was cut into 0.125-inch lengths in a rotary cutter, blended and part stored in sealed 2-lb. glass preserving jars for use in E.R.D.E. and distribution as required to other laboratories. The remainder was stored in a rubber bag in a wooden box. 15 firings of this propellant were carried out using the same calorimeter and bomb as in Series 1. Since the bomb had a capacity of 130 ml., a propellant charge of 12.9 g. plus 0.1 g. Mk. I cordite as igniter gave a density of loading of 0.1 g/ml. The procedure described in Section 4 was used, except that the water added from the measuring flask was weighed by difference.

The results of firings are given in Table 2 (p. 11). Column 2 gives the energy equivalent corrected to working conditions after adjusting for propellant charge, water in the calorimeter, and differences in weight of those bomb components which it had been necessary to replace. Column 3 gives the equivalent temperature rise using an extrapolation time of 2.6 minutes. Column 4 gives the total energy liberated i.e. (Column 2) x (Column 3). Columns 5 - 7 are self explanatory. Columns 8 - 12 give corrections in calories for air in bomb, igniter, and minor products.

Column 13 = (Column 4) - (Column 12) **and is the energy in calories produced by combustion of 12.9 g. standard SC.**

Column 14 = Figure in Column 13 divided by the charge weight of 12.9 g.

The mean calorimetric value of the SC propellant obtained from this series of firings is 955.6 cal/g. (water liquid).

The error in Series 2 (Section 7) is

$$b = \pm 100 \times \frac{2(\Sigma\Delta^2/n(n-1))^{\frac{1}{2}}}{\text{calorimetric value (mean)}} \text{ per cent}$$

Substituting values given in Table 2:

$$b = \pm 100 \times \frac{2 \times 0.31}{955.6}$$

$$= 0.0648 \text{ per cent.}$$

$$\text{Since } e = 2 \times \frac{0.717}{6318.12} = \pm 0.0227 \text{ per cent,}$$

the overall precision error

$$= (e^2 + c_1^2 + b^2)^{\frac{1}{2}}$$

$$= [(0.0227)^2 + (0.0462)^2 + (0.0648)^2]^{\frac{1}{2}}$$

$$= 0.0828 \text{ per cent.}$$

(The uncertainty interval is ± 0.8 calorie).

/Thus .....

Thus the calorimetric value of the sample of standard SC propellant Lot RNP 1141S when burnt in an inert atmosphere at a loading density of 0.1 g/ml., so that the products of combustion contain no methane or ammonium compounds, is 955.6 ± 0.8 thermochemical cal/g. (water liquid).

10. SERIES 3 - DETERMINATION OF THE ENERGY EQUIVALENT OF THE CALORIMETER UNIT WITH STANDARD SC PROPELLANT (LOT RNP 1141S) IN 150 ml. W.A. I HIGH-TENSILE STEEL BOMBS

A series of 11 firings was carried out using the procedure described in Section 4. The charge consisted of 14.9 grams standard SC propellant and an igniter of 0.1 gram Mk. I cordite. A 12th firing in which the air in the bomb was replaced by nitrogen, had a charge consisting of 15.0 grams SC cordite, 0.1 g. of which was used as igniter.

The water was added from the measuring flask but not weighed. The bomb, calorimeters and resistance thermometers were interchanged, each firing being carried out with a different combination. The combinations used in each firing are recorded in Table 6 (p. 14).

The results are summarised in Table 3 (p. 12). Column 12 is obtained from the corrected calorimetric value of the standard SC viz. 955.6 cal/g. Column 13 is obtained by adding total corrections to Column 12. Column 14 is obtained by dividing the figure in Column 13 by the equivalent temperature rise in Column 3. The energy equivalent of the initial system including the propellant charge is thus 3890.5 cal/deg.C.

The calibration error in the estimation of the energy equivalent of the calorimetric unit is

$$c_2 = \pm 100 \times \frac{2(\Sigma\Delta^2/p(p-1))^{\frac{1}{2}}}{\text{energy equivalent (mean)}} \text{ per cent}$$

$$= \pm 100 \times \frac{2 \times 1.36}{3890.2} \text{ per cent}$$

$$= 0.0696 \text{ per cent.}$$

Combining the calibration error of Series 3 with the precision error of the standard SC propellant (Section 9) gives the precision error of the energy equivalent of this calorimetric system:

$$\text{Precision error} = [(0.0828)^2 + (0.0695)^2]^{1/2}$$

$$= 0.1081 \text{ per cent}$$

corresponding to an uncertainty interval of ± 4.2 cal/deg.C.

The energy equivalent of the system is therefore 3890.2 ± 4.2 cal/deg.C.

/11. .....

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3. F.E. Smith, Phil. Mag., 1912, 24, 541.

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/TABLE 1 .....

TA

Determination of Energy Equivalent o
in Mk. XVI St

Expt. No.	Oxygen Pressure, atm.	Benzoic Acid		Equivalent Temperature Rise, T, deg.C	Total Energy Liberated in Experiment, (C x W) cal.	C T
		Mass in Vacuo, W, g.	Heat of Combustion under Bomb Conditions, C, cal/g.			
1	42	1.1684	6322.97	1.8408	7387.76	1
2	42	1.1564	6322.88	1.8237	7311.78	1
3	43	1.1868	6323.18	1.8664	7504.35	1
4	43	1.1602	6323.03	1.8261	7335.98	1
5	43	1.1622	6323.02	1.8310	7348.61	1
6	42	1.1637	6322.98	1.8313	7358.05	
7	41	1.1708	6322.82	1.8420	7402.76	1
8	38	1.1650	6322.48	1.8326	7365.69	1
9	42	1.1574	6322.95	1.8204	7318.18	1
10	43	1.1559	6323.10	1.8188	7308.87	1
11	41	1.0911	6322.72	1.7173	6898.72	1
12	41	1.1021	6322.64	1.7381	6968.18	1
13	35	1.0868	6321.85	1.7120	6870.59	1
14	43	1.1148	6322.92	1.7552	7048.79	1
15	43	1.0899	6322.95	1.7156	6891.38	1

Mean Energy Equivalent of Standard

Standard De

Ca

(1)

BLE 1

' Calorimeter Unit by Burning Benzoic Acid
inless Steel Bomb

Energy Produced by:			Energy Equivalent of System in Experiment, E_I, cal/deg.C	Correction Term for Standard Conditions, E_C, cal.	Energy Equivalent of Standard Initial System, E_{SI}, cal/deg.C
otton read, al.	HNO_3 Formation, cal.	Carbon Deposition, cal.			
6.30	1.52	-	4023.02	2.75	4020.27
6.69	1.17	-	4019.11	3.14	4015.97
9.41	1.52	-	4031.97	2.80	4029.17
8.63	1.11	-	4028.10	3.67	4024.43
8.24	1.24	-	4024.09	3.79	4020.30
7.86	0.97	-	4028.22	2.98	4025.24
7.08	0.83	0.79	4028.16	2.84	4025.32
6.03	1.24	1.58	4027.97	2.07	4025.90
7.47	0.55	0.79	4029.56	2.97	4026.59
7.47	0.00	1.58	4027.25	2.91	4024.34
6.30	1.38	-	4027.49	2.34	4025.15
6.69	1.11	-	4019.32	2.62	4016.70
8.63	0.83	-	4024.56	2.64	4021.92
6.30	0.97	-	4025.79	2.48	4023.31
7.86	1.11	0.79	4027.49	3.09	4024.40

Initial System = 4023.3 cal/deg.C

viation of Mean = 0.93 "

libration Error = 0.0462 per cent

/TABLE 2 .....

T

Determination of the Calorimetric Value

Mk. XVI Stai

Charge Wei

Expt. No.	Energy Equivalent of System Corrected for Firing Conditions, (E), cal/deg.C	Equivalent Temperature Rise, (T), deg.C	Total Energy Liberated in Experiment, (E × T), cal.	% Methane Formation by I.R.G.A.	Total Gas Volume, ml.	Total "Ammonia" Titration, ml. N/10 Acid
1	4029.05	3.1515	12697.55	0.24	10,470	2.7
2	4029.25	3.1505	12694.15	0.26	10,500	3.1
3	4029.75	3.1484	12687.26	0.26	10,440	3.5
4	4028.95	3.1494	12688.77	0.30	10,400	3.4
5	4028.95	3.1493	12688.37	0.27	10,500	3.5
6	4029.25	3.1505	12694.15	0.32	10,500	3.2
7	4028.95	3.1485	12685.15	0.34	10,490	3.0
8	4028.95	3.1501	12691.59	0.31	10,510	2.9
9	4030.26	3.1491	12691.69	0.29	10,610	2.5
10	4030.26	3.1459	12678.79	0.30	10,640	2.5
11	4030.57	3.1469	12683.80	0.35	10,620	4.0
12	4030.84	3.1460	12681.02	0.34	10,620	2.8
13	4029.64	3.1399	12652.66	0.30	10,670	2.0
14	4030.24	3.1475	12685.18	0.29	10,580	3.3
15	4030.64	3.1475	12686.44	0.34	10,530	2.7

Mean Calorimetric Value (Water Liquid) o

8 (1)

ABLE 2

(W/L) of Standard SC Propellant Lot RNP 1141S

nless Steel Bomb

ght = 12.9 g.

Energy Produced by:					Energy Liberated per 12.9 g. SC Propellant, cal.	Energy Liberated per g. SC Propellant cal.
Methane Formation, (A), cal.	Total "Ammonia" Formation, (B), cal.	Initial Air in Bomb, (C), cal.	Igniter (0.1 g. Mk.I Cordite), (D), cal.	Total (A + B + C + D), cal.		
65.01	8.68	143.0	123.6	340.29	12357.26	957.93
70.64	9.96	143.0	123.6	347.20	12346.95	957.13
70.22	11.25	143.0	123.6	348.07	12339.19	956.53
80.71	10.92	143.0	123.6	358.23	12330.54	955.86
73.36	11.25	143.0	123.6	351.21	12337.16	956.37
86.94	10.28	143.0	123.6	363.82	12330.33	955.84
92.37	9.64	143.0	123.6	368.61	12316.54	954.77
84.22	9.32	143.0	123.6	360.14	12331.45	955.93
79.61	8.03	143.0	123.6	354.24	12337.45	956.39
82.61	8.03	143.0	123.6	357.24	12321.55	955.16
96.20	12.85	143.0	123.6	375.65	12308.15	954.12
93.42	9.00	143.0	123.6	369.02	12312.00	954.42
82.87	6.43	143.0	123.6	355.90	12296.76	953.24
79.42	10.60	143.0	123.6	356.62	12328.56	955.70
92.66	8.68	143.0	123.6	367.94	12318.50	954.92

f SC Propellant Lot RNP 1141S = 955.6 cal/g.

Standard Deviation of Mean = 0.31 cal/g.

Calibration Error in Series 2 = 0.0648 per cent

/TABLE 3 .....

(2)

Determination of the Energy Equi
of Standard SC Propellant (Lot RN

Expt. No.	Mass of SC and of Mk.I Igniter, g.	Equivalent Temperature Rise, deg.C	Total Gas Volume at S.T.P., ml.	% Methane Formation by I.R.G.A.	Total "Ammonia" Titration, ml. N/10 Acid	Methane Formation, (A), cal.
1	14.900 0.100	3.7594	12,040	0.28	3.8	87.23
2	14.900 0.100	3.7633	12,060	0.30	3.2	93.62
3	14.900 0.100	3.7564	11,600	0.26	4.0	78.07
4	14.900 0.100	3.7564	12,090	0.26	4.0	81.36
5	14.900 0.100	3.7622	12,120	0.30	3.0	94.13
6	14.900 0.100	3.7712	12,190	0.29	3.6	91.47
7	14.900 0.100	3.7549	12,100	0.31	3.1	97.09
8	14,900 0.100	3.7564	11,900	0.32	3.0	98.56
9	14.900 0.100	3.7622	12,260	0.29	2.3	92.02
10	14.900 0.100	3.7609	12,260	0.32	2.7	101.54
11	14.900 0.100	3.7599	12,140	0.29	3.2	91.10
12	15.000	3.7170	12,270	0.31	4.2	98.40

Mean Energy Equivalen

Standard Deviation of

Calibration Error

Uncertainty Interval

(1)

TABLE 3

valent of Calorimeter Unit by Combustion
P 1141S) in 150 ml. W.A. I Gun Steel Bombs

Energy Produced by:				Energy Liberated per 14.9 g. SC Uncorrected for CH_4 & NH_3, cal.	Total Energy Liberated in Firing, cal.	Energy Equivalent of Standard Initial System ESI, cal/deg.C
Total Ammonia Formation, (B), cal.	Initial Air in Bomb, (C), cal.	Igniter 0.1 g. Mk.I Cordite, (D), cal.	Total (A + B + C + D), cal.			
12.21	165	123.6	388.04	14,238.44	14,626.48	3891.06
10.28	165	123.6	392.50	14,238.44	14,630.94	3888.11
12.85	165	123.6	379.52	14,238.44	14,617.96	3891.90
12.85	165	123.6	382.81	14,238.44	14,621.25	3892.77
9.64	165	123.6	392.37	14,238.44	14,630.81	3888.90
11.56	165	123.6	391.63	14,238.44	14,630.07	3879.42
9.95	165	123.6	395.64	14,238.44	14,634.08	3897.33
9.64	165	123.6	396.80	14,238.44	14,635.24	3896.08
7.39	165	123.6	388.01	14,238.44	14,626.45	3887.74
8.67	165	123.6	398.81	14,238.44	14,637.25	3891.95
10.28	165	123.6	389.98	14,238.44	14,628.42	3890.64
13.49	Nil	Nil	111.89	14,334.0	14,445.89	3886.44

t of System = 3890.2 cal/deg.C
Mean = 1.36 "
= 0.108 per cent
= ± 4.2 cal/deg.C

/TABLE 4 .....

2

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TABLE 4

Extrapolation Times of Different Experimental Series

Series No.	Bomb	System	Experiment No.	Extrapolation Time, min.	Mean Extrapolation Time, min.
1	Mk. XVI stainless steel	Benzoic acid in oxygen	2 4 5 6 7	4.0 3.2 3.2 3.2 3.2	3.2
2	Mk. XVI stainless steel	Standard SC cordite RNP 1141S	1 4	2.6 2.6	2.6
3	W.A. I gun steel	Standard SC cordite RNP 1141S	3 4	1.55 1.45	1.5

/TABLE 5 .....

TABLE 5

Weights of the Interchangeable Items in the Calorimeter Units

Item	Weight, g.	Tolerance, g.
Bomb head (without accessories)	1459.0	± 0.05
Accessories:		
valve	71.7	± 0.1
electrodes	10.5	± 0.05
non-metallic parts	6.6	± 0.05
Bomb body	6442.75	± 0.15
Platinum resistance thermometer	388.6	± 0.05
Calorimeter can	4467.2	± 0.05

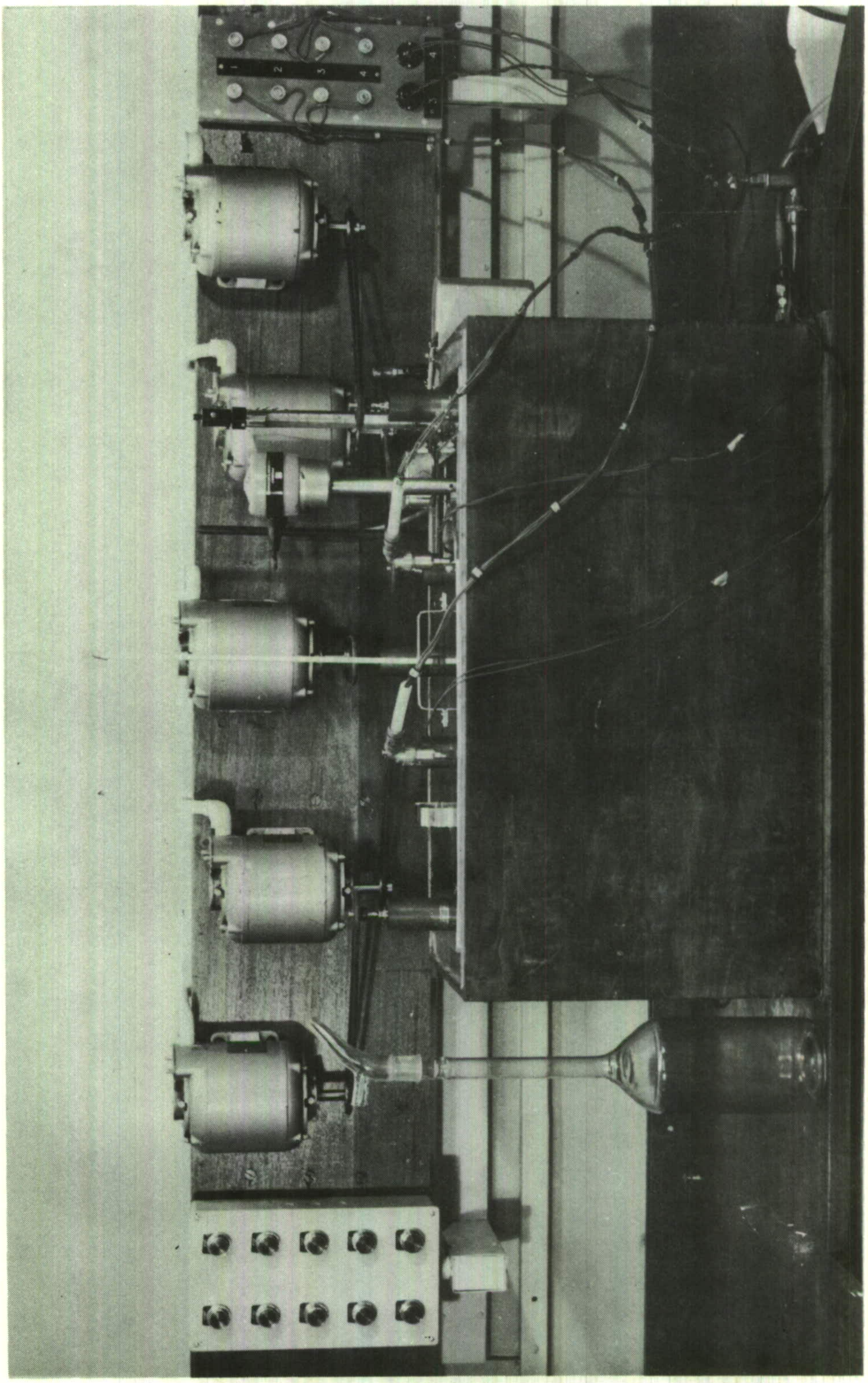
TABLE 6

Disposition of Apparatus in Series 3 Firings

Experiment No.	Bomb			Calorimeter	Thermometer
	Body	Head	Valve		
1	4	2	1	1	1
2	1	4	2	1	1
3	3	4	5	1	1
4	4	4	1	2	1
5	1	5	2	3	3
6	1	5	2	1	1
7	4	1	4	2	2
8	3	3	3	1	1
9	3	3	3	3	3
10	1	1	1	4	4
11	1	1	1	3	3
12	3	3	3	4	4

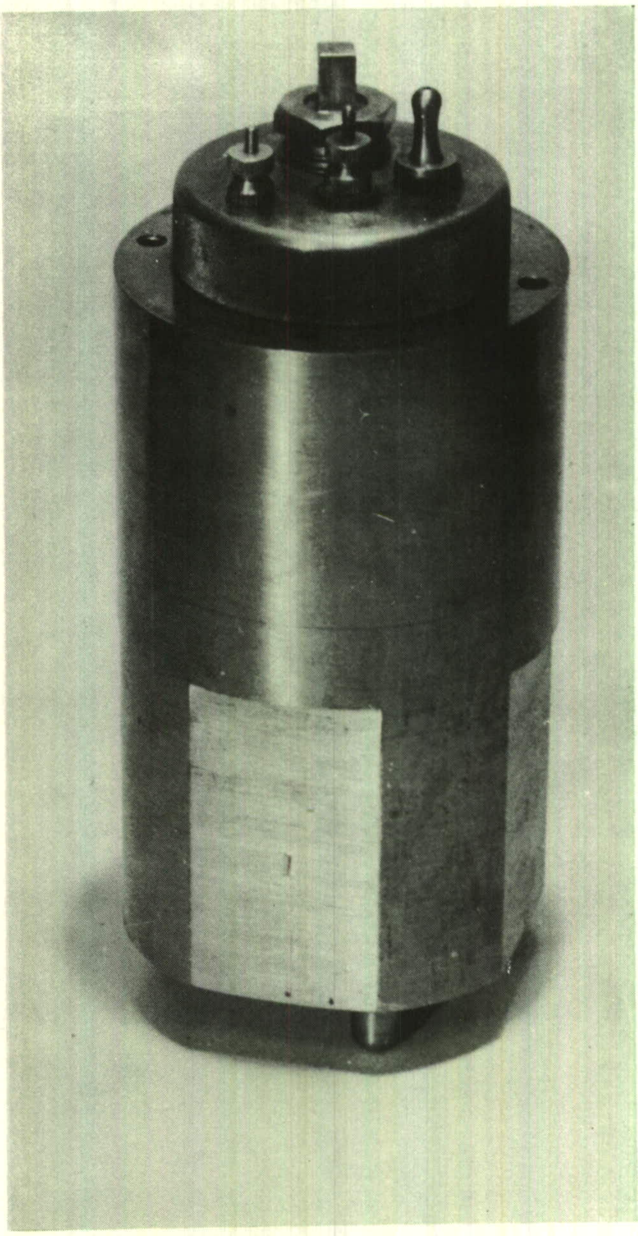
Heaviest Combination used in Experiment No. 1
Lightest Combination used in Experiment No. 2

S. No. 808/62/BL



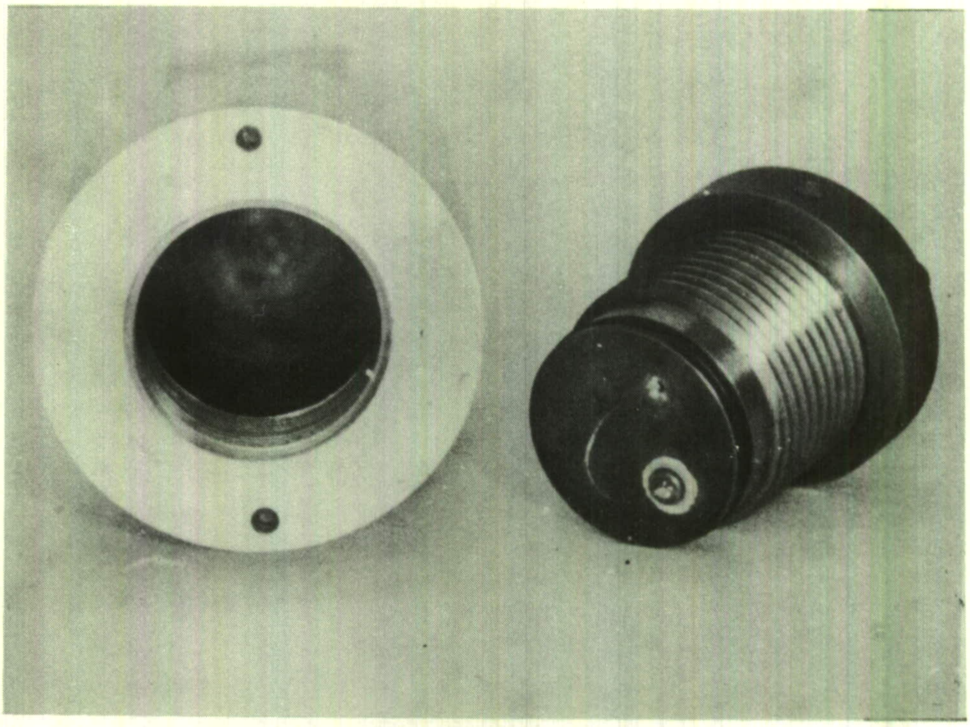
TWIN CALORIMETER UNIT

FIG. 1



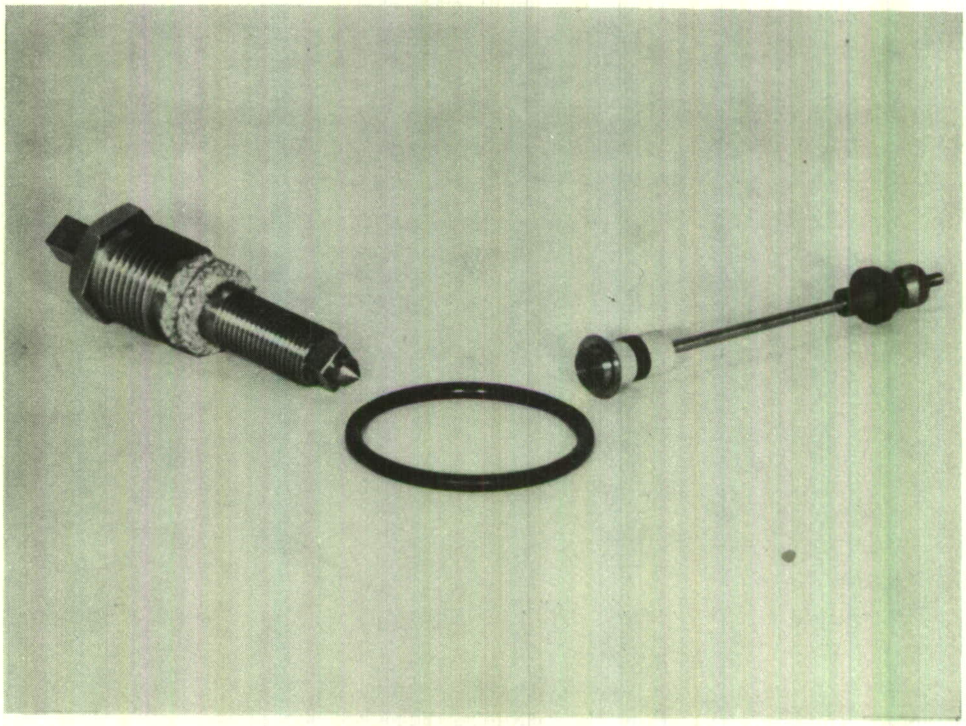
150 ml Capacity High-Tensile Steel Calorimeter Bomb

Fig. 2



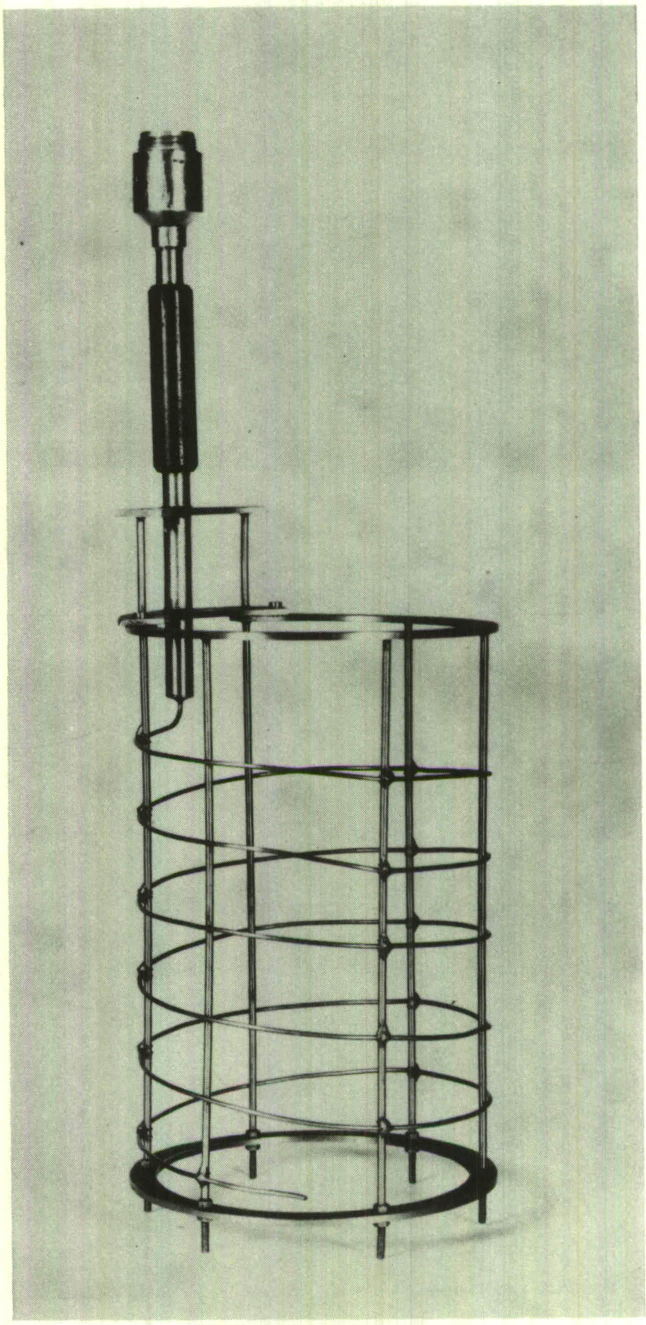
CALORIMETER BOMB – VIEW OF HEAD AND BOMB INTERIOR

FIG. 3



"O" RING, VALVE AND ELECTRODE ASSEMBLIES FOR CALORIMETER BOMB

FIG. 4



PLATINUM RESISTANCE THERMOMETER

FIG. 5

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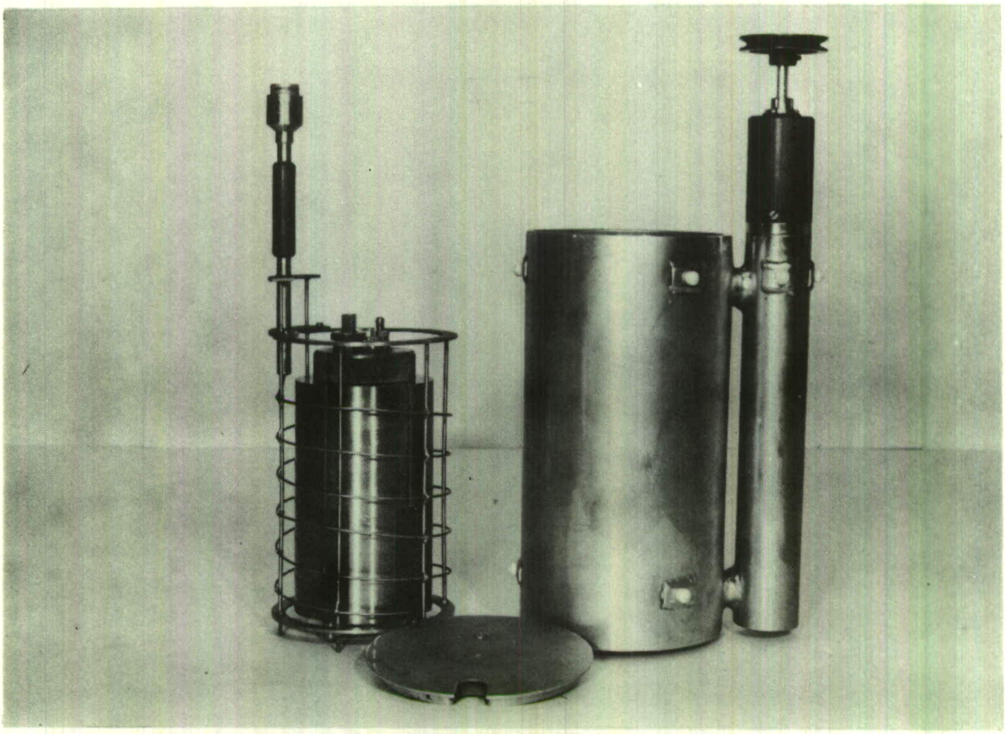

CALORIMETER CAN WITH PLATINUM RESISTANCE THERMOMETER AND CALORIMETER BOMB

FIG. 6

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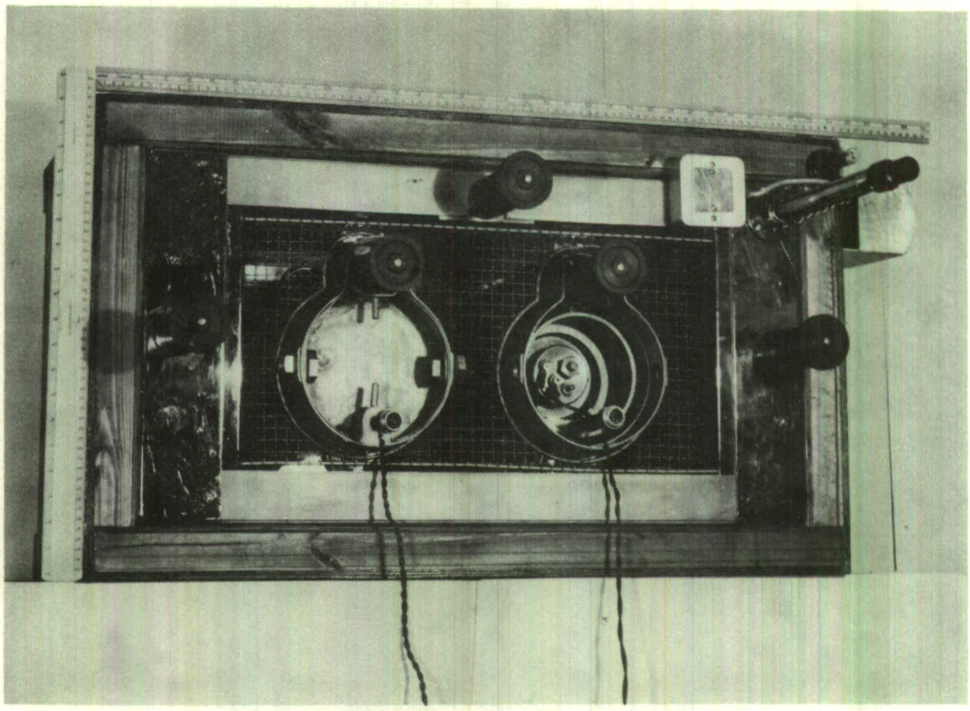
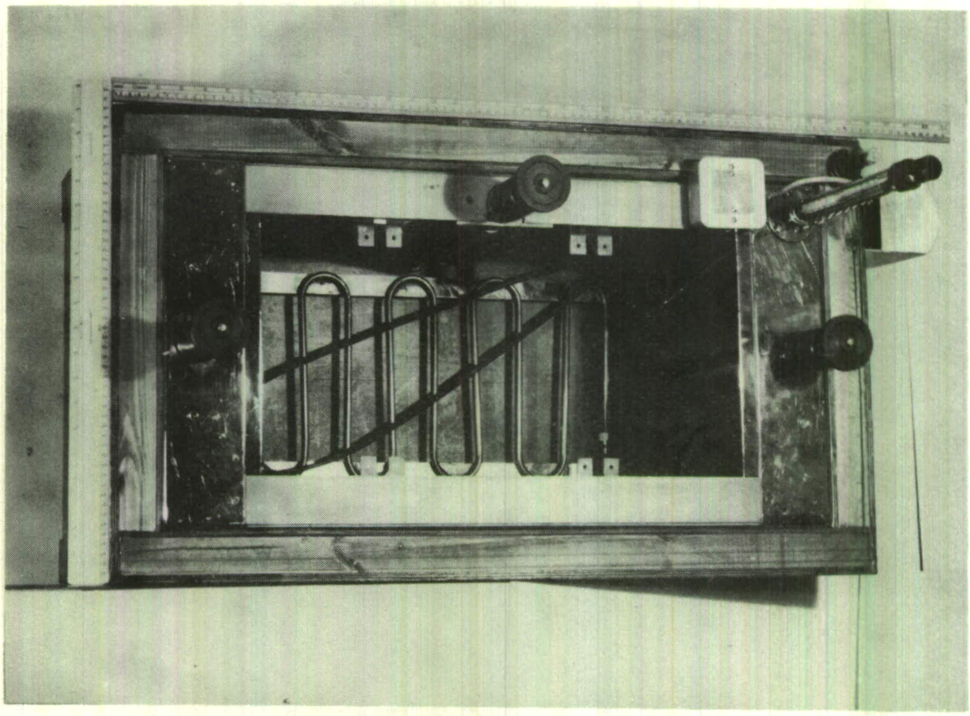


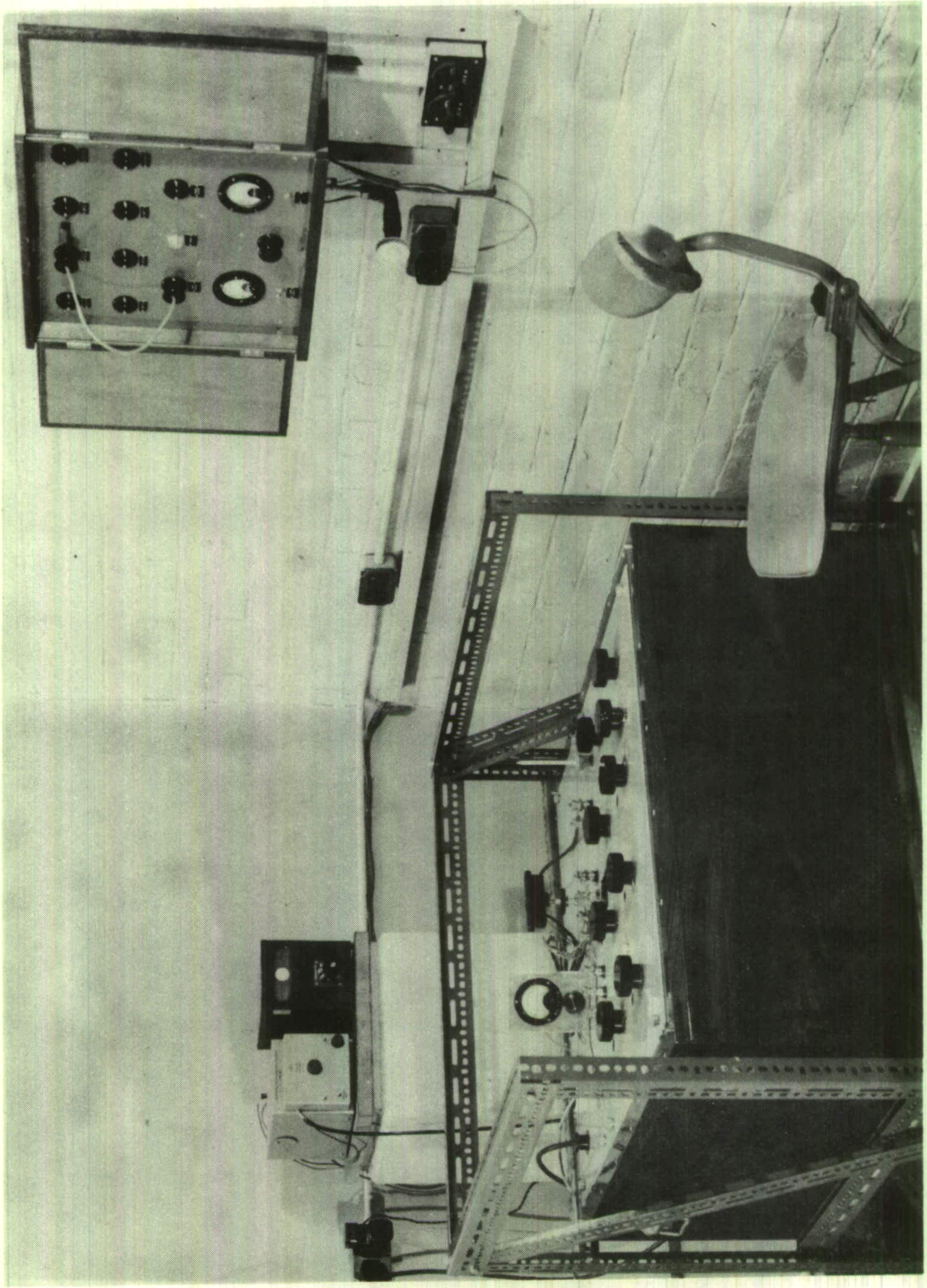
VIEW OF THERMAL SHIELD, SHOWING CALORIMETER BOMB AND PLATINUM RESISTANCE THERMOMETER IN PLACE

FIG. 7



INTERIOR VIEW OF THERMAL SHIELD, SHOWING DETAILS OF CONSTRUCTION

FIG. 8



SMITH'S No. 3 DIFFERENCE BRIDGE, WITH TINSLEY PHOTOCELL GALVANOMETER AMPLIFIER AND FIRING PANEL

FIG. 9

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E.R.D.E. Technical Memorandum No. 10/M/62

Calorimetry of Double-Base Propellants: An Account of the E.R.D.E. Propellant Calorimeter Installation and Determination of Energy Equivalent

G.E. Colley, L.E. Grindrod, D.L. Hodge and J.H. Littlefair

November, 1962

An account is given of a 150 ml. bomb calorimeter developed in E.R.D.E. and installed in Government propellant factories and Service Inspectorate laboratories for quality control and inspection in double-base propellant manufacture.

The preparation of a standard SC propellant and the measurement of its calorimetric value, using the combustion of benzoic acid in oxygen in a stainless steel bomb as standardising reaction, and the determination of the energy equivalent of the calorimeter with normal high-tensile steel bombs using this standard SC propellant are described.

Precision errors are of the order of 0.1 per cent.

14 pp., 9 fig., 6 tables.

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